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Determining the technological properties of laminated windows as a component of sustainable facade design

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Abstract

Wood is an environment-friendly, durable and sustainable material which gives spaces a warm and natural look. The construction industry, which uses many types of materials together in terms of its components, focuses on efficiency in building materials in order to offer aesthetic, economical and ergonomic solutions as a result of today's architectural approaches. In the construction sector, the use of wood has become widespread in facade design and window production especially with the increasing importance of environmental awareness and sustainability in the 21st century. In this study, black pine (*Pinus nigra subsp*. pallasiana) has been used as the wood material. The test samples consist of three layers. Urea-formaldehyde glue was used for bonding the test samples. Following the physical and mechanical experiments conducted during the research process, it was determined that the technological characteristics of the window profile produced from three-layer laminated black pine wood are superior to the technological characteristics of the solid window profile representing its own species. In order to achieve sustainability goals, it can be recommended to use laminated wooden window profiles in buildings.

Keywords: Sustainability, window profile, wood, technological properties

Sürdürülebilir cephe tasarımının bir bileşeni olarak lamine pencerelerin teknolojik özelliklerinin belirlenmesi

Öz

Ahşap, mekanlara sıcak ve doğal bir görünüm kazandıran çevre dostu, dayanıklı ve sürdürülebilir bir malzemedir. Bileşenleri açısından birçok malzeme türünü bir arada kullanan inşaat sektörü, günümüz mimari yaklaşımları neticesinde estetik, ekonomik ve ergonomik çözümler sunmak amacıyla yapı malzemelerinde verimliliğe odaklanmaktadır. İnşaat sektöründe özellikle 21. yüzyılda çevre bilincinin ve sürdürülebilirliğin öneminin artmasıyla birlikte cephe tasarımında ve pencere üretiminde ahşabın kullanımı yaygınlaşmıştır. Bu çalışma; bina cephesinin tasarımında sürdürülebilirlik hedeflerine ulaşmak için önemli bir rol oynayabilecek ahşap lamine pencere profilinin bazı teknolojik özelliklerini belirlemek için yapılmaktadır. Bu çalışmada ahşap malzeme olarak, karaçamdan (*Pinus nigra subsp*. pallasiana) kullanılmıştır. Deney örnekleri üç katmandan oluşmaktadır. Deney örneklerinin yapıştırılmasında üre-formaldehit tutkalı kullanılmıştır. Araştırma sürecinde gerçekleştirilen fiziksel ve mekanik deneyler sonunda, üç katmanlı olarak lamine edilmiş karaçam odunundan üretilen pencere profilinin teknolojik özelliklerinin, kendi türünü temsil eden masif pencere profilinin teknolojik özelliklerinden daha üstün olduğu tespit edilmiştir. Sürdürülebilirlik hedeflerine ulaşmak amacıyla, yapılarda lamine ahşap pencere profili kullanılması önerilebilir.

Anahtar kelimeler: Sürdürülebilirlik, pencere profili, ahşap, teknolojik özellikler

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1 Introduction

Windows, which are used in architecture for natural lighting, ventilation and decorative purposes, are an essential building component for living spaces. Windows designed and manufactured in proportion to the space add value to the building in terms of design as well as architecture. Upon examining historical structures, it becomes evident that artistic and aesthetic elements frequently coalesce on building facades with windows standing out as a crucial focal point. Wooden window example is displayed in Figure 1.

Figure 1. View of a wooden window of an old building in Kırklareli (Yüksek, 2005).

The window types used in Turkish houses are manufactured with methods called vertical and guillotine, and the main factors in choosing these methods are lighting, security and heat/sound insulation as well as privacy (Saka and Kahraman, 2020).

Depending on atmospheric conditions, physical deformation and dimensional instability are frequently observed in windows manufactured with materials mostly wood, PVC, aluminium, etc. It is crucial to ascertain the choice of window products in facade designs considering factors such as the building's characteristics, location, daily sunlight exposure and temperature fluctuations.

The wood used for wooden window profiles can be obtained in accordance with the principles of sustainable forest management. Sustainable forestry involves cutting down trees in a balanced manner ensuring that forestry does not harm ecosystems and regrowth of trees. In this way, forest resources are protected and long-term wood supply can be ensured. Wooden window profiles have a relatively lower carbon footprint than other materials. Wood absorbs carbon dioxide as it grows and stores this carbon. Wooden products retain this carbon throughout their lives. Additionally, processing and manufacturing wood is generally less costly in terms of energy which can contribute to energy savings. Wood is a natural material and can be produced without harming the environment. It can be processed and recycled without the need for chemical treatments. Wooden window profiles naturally provide good thermal insulation. This is advantageous in terms of energy efficiency because it blocks outside heat from entering the interior and reduces heat loss. This can reduce heating and cooling costs. Wooden window profiles can last for many years when properly maintained. This can contribute to less material consumption and longer use of resources.

Structural laminated wood is a prefabricated wood building element created by bonding independent wood layers of varying dimensions under controlled industrial conditions with special adhesives. Structural laminated wood systems offer structural features such as a reduction in dead load and seismic load, a high strength-to-density ratio similar to steel, high fire resistance, low transportation cost and a rapid construction process compared to steel and reinforced concrete systems. In addition to these structural characteristics, the system provides opportunities for durable and sustainable construction due to its low heating and cooling requirements in building envelope design as well as its impact on acoustic comfort levels inside the space, negative carbon footprint feature and contribution to the life cycle process of the structure (Ceylan and Girgin, 2019).

For many users, the price parameter plays an important role in window profile selection. Although the frequency of use of PVC window profiles has increased, wooden profiles, which are still an element of choice, find use due to their ease of maintenance. The issue of workability, is which a significant drawback of natural wood, leads to both technical and aesthetic complications in the material. The lamination technique, which is frequently preferred to eliminate this drawback, eliminates the drawbacks of wood and significantly increases its lifespan (Kucuktuvek, 2002).

According to Keskin (2003), utilizing solid wood material as a single piece for large and curved elements serves to avoid concerns such as knots, cracks and spiral fibers in the wood. Recognizing the impracticality of completely eliminating these imperfections, attempting to do so would not be feasible from both an economic and technical standpoint.

Wooden laminated elements are preferred in the industry due to their high formal stability as a semi-finished material, their closest properties to wood material compared to other composite materials and their flexibility in shaping. It is frequently used in the furniture industry especially in various construction elements such as laminated materials, columns, beams, arches and trusses. The use of laminated materials provides various advantages in terms of technical, aesthetic, economic and eases of production especially in curved furniture elements (Kahraman and Altunok, 2017). Indeed, it was stated in a particular study that Scots pine (*Pinus sylvestris* L.), which grows in our country, can be preferred in the production of laminated beams obtained by using wooden materials (Öztürk and Arıoğlu, 2006).

The lamination process enables the production of window profiles suitable for the facade design by providing advantages such as saving raw materials in wood materials, minimizing the defects seen in the material, ensuring quality optimization in the material, reducing material work depending on atmospheric conditions and dimensional flexibility in terms of efficient use of the material.

The lamination technique was first used in chair production in our country in 1987 by a private company in Istanbul. Later, private companies in Ankara and Tekirdağ used this technique in joinery construction. It is known that products produced using the lamination technique had become more widespread after 1990 (Dilik, 1997).

The study delved into the mechanical impacts of lamination and analyzed various physical and mechanical attributes of laminated Scots pine wood. Within this context, it was established that the five-layer laminated wood material bonded with polyvinyl acetate (PVAc-D4) adhesive exhibited distinct advantages in terms of both physical and mechanical properties when compared to the solid material derived from Scots pine wood (Keskin, Atar and Kurt, 2003).

Güler et al., (2007) determined that the dimensional stabilization of laminate flooring used as building elements is directly related to the glue used in parquet manufacturing. In support of this, it has been observed that significant advantages are obtained depending on the glue types and wood species in the pressure, bending and adhesion resistance measurements made on laminated materials obtained by using different wood types and glues (Perçin et al., 2009). In a study conducted by Kahraman and Altunok (2016), papel veneers of oriental beech (*Fagus orientalis* Lipsky), sessile oak (*Quercus petraea* Lieble) and Scots pine (*Pinus sylvestris* L.) each with a thickness of 1.5 cm were affixed using PVAc dispersion D4 glue onto a vacuum membrane press. Curved laminated wood samples comprising 13 layers were subsequently obtained and subjected to diagonal tensile testing. The results indicated that the highest level of adhesion quality was observed in the panel manufactured using pellets derived from oriental beech (*Fagus orientalis* Lipsky) wood (Kahraman and Altunok, 2016).

The aim of this study is to determine the technological properties of black pine wooden laminated window profiles that can play an important role in achieving sustainability goals in the design of the building facade. In this context, laminated boards and solid forms obtained from the same tree species are compared separately.

2 Material and Method

2.1 Wood

Black pine (*Pinus nigra subsp*. pallasiana), which is widely used in window profile production in our country, was used in the research. Wooden material was obtained from the Afyonkarahisar wood industry by random selection method. The wood material was selected by ensuring that it was knot-free, ridge-free, resin-free, growth defects-free, solid, smooth-fibered and sapwood. The black pine wood used in the study has very wide sapwood (half the diameter), yellowish and reddish white, and with reddish brown heartwood. In the cross section, it is dull and in the tangential section summerwood strips are darker in colour than Scots pine.

The full dry density of black pine wood, which is preferred in our country's forest industry, is 0.52 g/cm^3. The pressure resistance parallel to the fibers is 479 kg/cm^2 and the tensile strength is 23.4 kg/cm^2. It is used as a building material because it has good nail retention resistance and is easy to process (Örs and Keskin, 2001). Table 1 displays the physical and mechanical properties of black pine.

Table 1. Average values of physical and mechanical properties of black pine (Bozkurt, 1986).

Air dry density values (gr/cm^3)		0.56
Shrinkage amount (%)	β_R	5.58
	β_T	8.19
	β_L	0.23
	β_V	13.9
Compressive Strength (// N/mm^2)		47.9
Bending Strength (⊥N/mm^2)		109.6
Modulus of Elasticity (N/mm^2)		-
Shear strength (// N/mm^2)		6.71

β_R: Radial Shrinkage (%), β_T: Tangential Shrinkage (%), β_L: Longitudinal Shrinkage (%), β_V: Volume Shrinkage (%)

2.2 Glue

The glue used in the study is urea-formaldehyde glue supplied by Polisan Company in Kocaeli, Turkey and this type of glue is preferred in the woodworking industry. It was assessed that urea-formaldehyde glue could be employed in the manufacturing of door and window frames when the studies were examined (Örs, 1981).

The urea-formaldehyde glue utilized in this study is a product derived from the condensation reaction of urea and formaldehyde obtainable in either dry or liquid form. The properties of the resulting glue are determined by factors such as temperature, reaction time, pH value, catalyst concentration and the molar ratio of urea-formaldehyde (Çolakoğlu, 2001). Table 2 provides an overview of the technological characteristics of the urea-formaldehyde glue employed in the research.

Table 2. Properties of urea-formaldehyde adhesive

Type	Polyurea – 8755
Appearance	Clear, White liquid
Solid content (2 hours at 120 °C)	55 ± 1% (by volume)
Density (20 °C)	1.220 - 1.240 gr/cm^3
Viscosity (20 °C)	250 - 400 cp
pH (200 °C)	7.5 - 8.5
Free formaldehyde	1% max
Gelation time (100 °C)	35 - 45 Seconds
Storage time (20 °C)	60 days
Mixture	50 g resin + 5 mL 10% NH_4Cl
Hardener	20% maleic acid was used in the research

2.3 Preparation of test samples

The timbers measuring (10x10x100 cm) to be used in the production of the test samples were stored in a ventilated environment away from direct sunlight and stored for approximately one year according to TS 2471 (1976) standard. Thus, the air-dried parts were kept in the climate chamber at 20 ± 2 °C temperature and 65 ± 5% relative humidity until they reached the equilibrium humidity (12%). Then, the air-dried wood material was cut to rough dimensions on a band saw and planed, and lamellas were produced by making them 20 mm thickness in a thickening machine. Then, the lamination process was carried out. Gluing was done with a brush during the lamination process and the glue manufacturers' instructions were followed. Cold pressing was used in the lamination process. The wood moisture content was 12%, the used amount of glue was 150-170 gr/m^2, the pressing pressure was 0.5 N/mm^2 and the pressing time was 30 minutes in the pressing process. One week after the lamination process, the profiles were cut with a circular saw machine to dimensions of 60 × 90 × 800 mm in the L-type shape which was chosen considering that they are widely used in window production. Afterwards, test and measurement samples were prepared from the window profiles by taking into account the following test standards. 3-layer laminated samples were prepared for experiments and measurements that cannot be made in 1/1 dimensions. The perspective view of the experimental sample prepared for the research is shown in Figure 2.

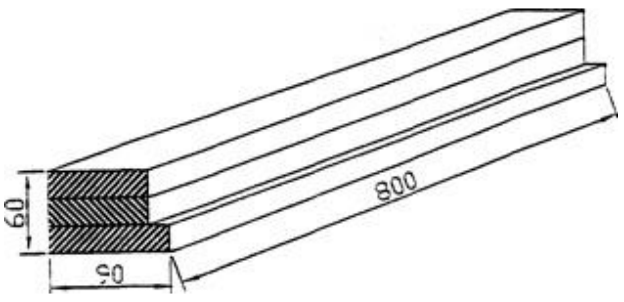

Figure 2. Window profile produced with lamellas of equal thickness

2.4 Test method

In the trials carried out within the scope of the research study, the test methods used in the standards for solid wood materials were chosen as the trial methods as it was aimed to determine the physical and mechanical properties of laminated window profiles as well as to compare them with the properties of solid wood. In this context, experiments and measurements regarding the physical and mechanical properties suitable for window and laminated materials were carried out.

Experiments were carried out to determine compressive strength, bending strength, modulus of elasticity and shear strength values regarding to laminated window profiles of this research. In addition, air-dry density values and dimensional deformation amounts of the material were also measured.

2.4.1 Determination of air dry density

The samples for density determination were fabricated following the guidelines outlined in TS 2471 (1976). A total of 20 experimental and 10 control samples, each measuring 60 × 70 × 30 mm (1/1), were prepared by drawing reference from the TS 2472 (1976) standard. Then, these samples were stored in a climate-controlled chamber at a temperature of 20 ± 2 °C and a relative humidity of 65 ± 5% until they reached a stable weight. Subsequently, they were weighed using an analytical balance, their dimensions were measured using a micrometer digital caliper and the volumes were computed. The air-dry density (δ_{12}) values were then calculated using the following equation:

$$\delta 12 = \frac{M12}{V12} \; \frac{g}{cm^3} \qquad \text{Eq. 1}$$

where, M_{12} denote the air dry weight (g) and V_{12} denote the air-dry volume (cm^3).

2.4.2 Determination of shrinkage amount

TS 4083 (1983) and TS 4084 (1983) principles were followed in the experiments to determine the amount of shrinkage. For this purpose, 20 experimental and 10 control samples were prepared with dimensions of 60 × 70 × 30 mm. Subsequently, the digital caliper accurate to 0.01 accuracy was employed to gauge the gap between the designated points on two perpendicular sections of the samples. These samples had been immersed in clean and quiescent water at 20 °C for 24 hours elevating their moisture level beyond Fiber Saturation Point (FSP). In the following, the identical samples were subjected to drying in a cabinet set at 103 ± 2 °C until their weight stabilized after which they were allowed to cool within a desiccator. In this case, the shrinkage percentages (β) were measured again from the first measurement points:

$$\beta = \frac{L_{max} - L_{min}}{L_{max}} \qquad \text{Eq. 2.}$$

Where, Lmax is wet dimension, Lmin is dry dimension.

2.4.3 Determination of compression strength

A total of 20 air-dried laminated and three layers test samples and 10 laminated control samples, which are each measuring 20 × 20 × 30 mm in accordance with TS 2595 (1976) standard, were employed to assess the compressive strength parallel to the grain and the adhesive line. The performance of compression strength tests is displayed in Figure 3. The cross-sectional area where force would be exerted on the samples was measured before conducting the experiments. Subsequently, the maximum force (Fmax) at the point of fracture during the experiment was ascertained and the compressive strength of the samples was calculated using the following equation:

$$\sigma = \frac{Fmax}{A} \frac{N}{mm^2} \quad \text{Eq. 3.}$$

Where, σ is the Compression strength (N/mm^2), Fmax is the Maximum force (N), A is the area where force is applied (A).

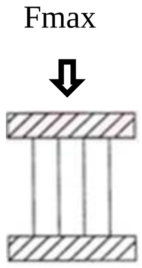

Figure 3. Compression strength test

2.4.4 Determination of bending strength

Adherence to TS EN 310 (1999) and TS 2474 (1976) standards was ensured to ascertain the bending strength by taking into consideration the prevailing laboratory conditions. For this purpose, a total of 20 experimental and 10 control samples, which are each measuring 20 × 20 × 360 mm, were prepared. The experiments were conducted utilizing a computer-controlled universal testing machine with a capacity of 1000 kN. The bending strength test is illustrated in Figure 4. The bending strength determined by the maximum force at fracture (Fmax) was computed by using the following equation.

In this equation;

$$\sigma e = \frac{3.Fmax.L}{2.b.h^2} \frac{N}{mm^2} \quad \text{Eq. 4.}$$

Where, σe is the Bending strength (N/mm^2), Fmax is the breaking load (N), L is the span length (mm), b is the Width of the sample (mm), h is the Thickness of the sample (mm)

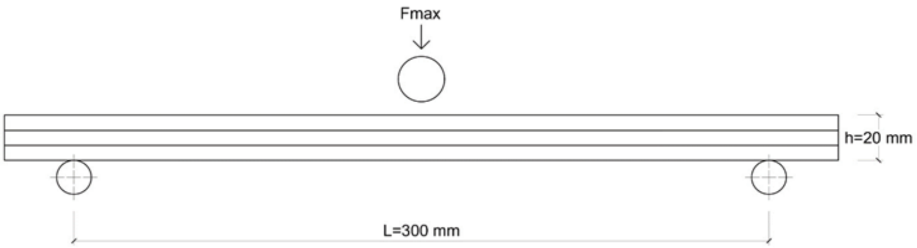

Figure 4. Bending strength test

2.4.5 Modulus of elasticity in bending

In order to determine the bending strength, TS EN 310 (1999) and TS 2478 (1976) standards were complied with taking into account the current laboratory conditions. For this purpose, 20 experimental and 10 control samples were prepared with dimensions of 20 × 20 × 360 mm. The modulus of elasticity was calculated for the force difference Fmax applied in the elastic deformation region according to the formula below with the help of the difference f in the bending amounts in the sample.

$$E = \frac{\Delta F . I^3}{4.b.h^3.f}$$ Eq. 5.

In this equation; ΔF is load equal to the difference between the lower and upper F forces in the region where elasticity is measured, I is span length (mm), b and h are cross-sectional dimensions of the test piece (mm), f is the deflection due to the load F applied at the middle of the beam.

2.4.6 Determination of shear strength

In the research, 20 test and 10 control samples were prepared from L-type sample profiles measuring 60 × 60 × 90 by taking into account the ASTM D 3110 (1995) standard used for this purpose. Shear strength was calculated according to the formula below:

$$\sigma m = \frac{Fmax}{b.l} \frac{N}{mm^2}$$ Eq. 6.

In this equation; σm is shear strength (N/mm^2), Fmax is breaking load (N), b is adhesion surface (mm), *l* is defined as the adhesion surface length (mm).

Figure 5. Shear strength test parallel to fibers and glue line

In the shear strength test, the shear strength of the profiles was calculated in the perpendicular (⊥) direction to the fibers. Additionally, breakage patterns were observed during the trials and care was taken to exclude samples showing glue breakage (fiberless separation) from being evaluated.

3 Results and Discussion

In this section, findings regarding the technological properties of laminated and solid window profiles and comparisons with the literature within the framework of the findings are included. Each technological experiment is examined separately under separate headings.

3.1 Air dry density

Statistical values of air-dry density of laminated and solid window profiles are given in Table 3.

Table 3. Air Dry density test results

Statistical Value	Laminated Black Pine	Solid Black Pine
x (g/cm^3)	0.5986	0.5719
s (g/cm^3)	0.022246	0.0168
v (s^2)	0.000495	0.0003
min (g/cm^3)	0.562	0.543
max (g/cm^3)	0.637	0.601
N	20	10

x=arithmetic mean, v=variance, s=standard deviation ,N=number of samples

Upon analyzing the gathered data, it was observed that the air-dry density of the laminated black pine window profile exceeded that of the solid window profile. The air-dry density for the control samples employed in the experiment was recorded at 0.57 g/cm³ as depicted in Figure 6. In Bozkurt's (1986) study, the air-dry density of solid black pine was determined to be 0.56 g/cm³. This suggests that the experimental findings align with existing literature. Furthermore, it was noted that the air-dry density of laminated black pine (0.6) surpassed that of the control samples. This discrepancy is likely attributed to the adhesive employed in the lamination process (σ = 1,230 g/cm^3).

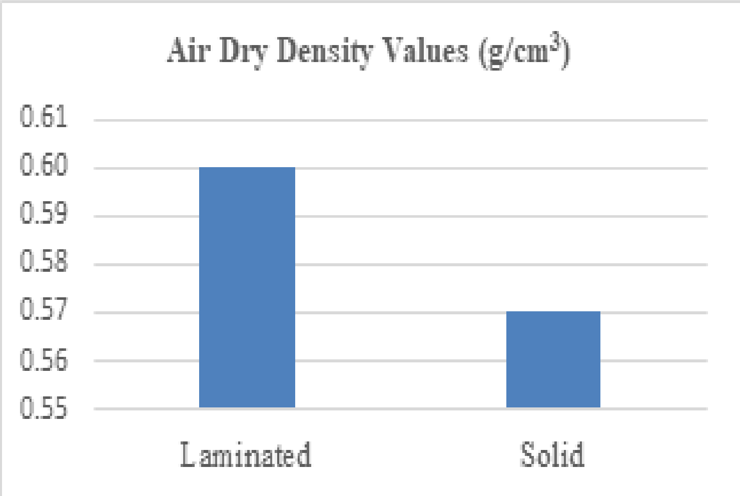

Figure 6. Air-dry density histogram graph

3.2 Determination of the shrinkage amount

Statistical values of the shrinkage amounts of laminated and solid window profiles are given in Table 4.

Table 4. Shrinkage amount values

Statistical Value	Laminated Black Pine				Solid Black Pine			
	βR	βT	βL	βV	βR	βT	βL	βV
x (%)	4.544	7.316	0.363	12.223	4.763	7.762	0.376	12.889
s (%)	0.3012	0.4865	0.0345	0.4830	0.1783	0.3732	0.0324	0.3944
v (s^2)	0.0907	0.2367	0.0012	0.2333	0.0318	0.1393	0.0010	0.1556
min (%)	4.16	6.58	0.28	11.32	4.5	6.88	0.32	12.2
max (%)	5.21	8.21	0.42	12.88	5.02	8.14	0.42	13.48
N	20	20	20	20	10	10	10	10

x:arithmetic mean, v:variance, s:standard deviation, N:number of samples

The shrinkage of the laminated black pine window profile was less than that of the solid window profile. The histogram chart created within the framework of the obtained data can be seen in Figure 7.

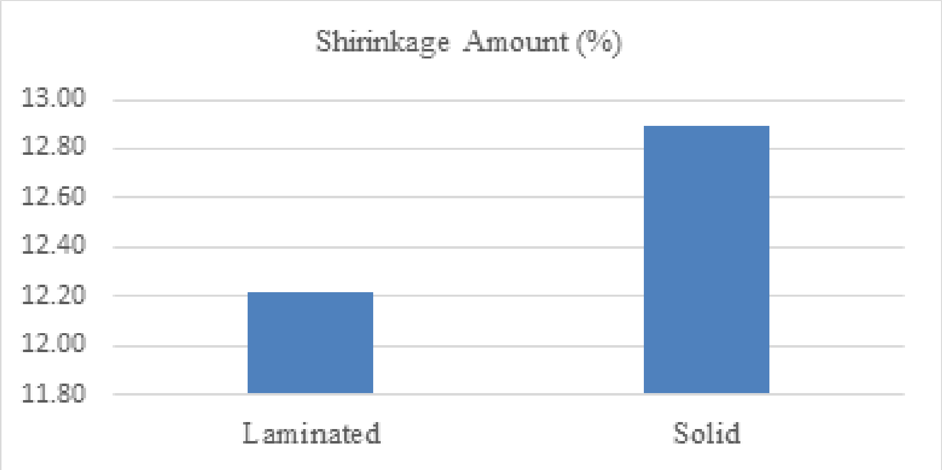

Figure 7. Histogram graph of shrinkage amount

In the literature, the shrinkage amount of solid black pine is given as 13.9% (Bozkurt, 1986). These values are greater than the shrinkage values of the control samples used in the experiment. The shrinkage amount of laminated black pine was found to be less than the control samples. This may be due to the adhesive used in the lamination technique preventing the movement of water in the wood cell wall.

3.3 Compression strength

In light of the data obtained in the study, it was observed that the compression strength value of the laminated window profile was higher than the control samples. Statistical values of compression strength (parallel to grain) of laminated and solid window profiles are given in Table 5.

Table 5. Compression strength values

Statistical Value	Laminated Black Pine	Solid Black Pine
x(N/mm^2)	61.24	55.56
s(N/mm^2)	0.1818	0.1981
v(s^2)	0.0331	0.0392
Min (N/mm^2)	58.6	52.4
Max (N/mm^2)	65.2	58.8
N	20	10

x=arithmetic mean, v=variance, s=standard deviation, N=number of samples

In a study conducted by Bozkurt (1986), the compression strength of solid black pine was determined as 47.9 N/mm^2. At the end of the pressure test, it is seen that the compression strength values of solid black pine samples are higher than those determined in the literature. The compression strength histogram graph is shown in Figure 8.

The compressive strength of the laminated black pine window profile was observed to surpass that of the control samples. This could be attributed to the adhesive applied in the lamination process permeating between the wood fibers, thereby augmenting the cohesive force.

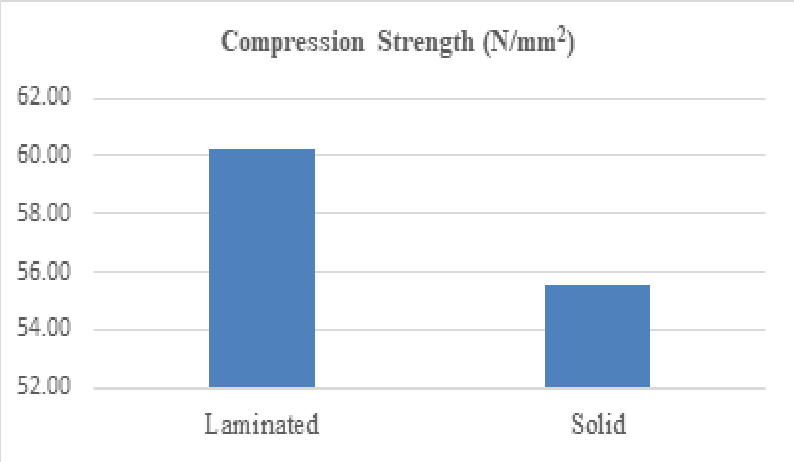

Figure 8. Compression strength histogram graph

3.4 Determination of bending strength

Statistical values of bending strength of laminated and solid window profiles obtained as a result of the study are given in Table 6.

Table 6. Bending strength values

Statistical Value	Laminated Black Pine	Solid Black Pine
x (N/mm^2)	131.173	112.804
s (N/mm^2)	5.5819	5.3742
v (s^2)	31.1576	28.8829
min (N/mm^2)	123.58	105.35
max (N/mm^2)	143.36	121.02
N	20	10

x=arithmetic mean, v=variance, s=standard deviation, N=number of samples

The bending strength value of the laminated black pine window profile was found to be higher than the solid window profile. Bending strength test results are shown in Figure 9.

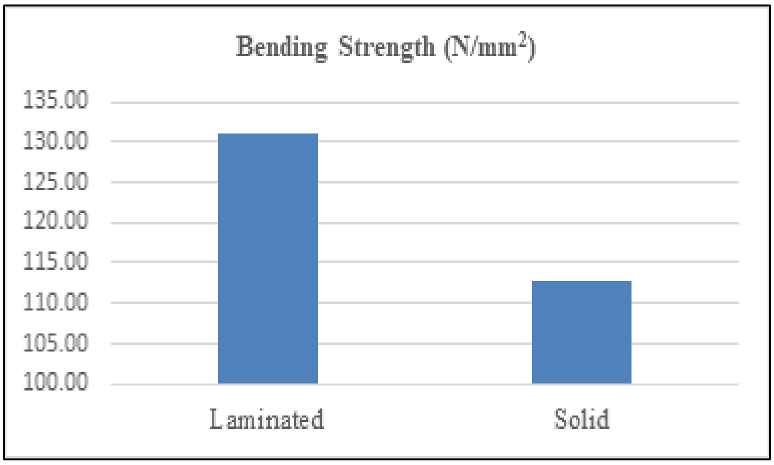

Figure 9. Bending Strength

In the literature, the bending strength value of solid black pine is given as 109.6 N/mm^2 (Bozkurt, 1986). This value is less than the bending strength values of the control samples used in the experiment. The laminated black pine window profile bending strength value was found to be greater than the control samples. This may be due to the glue used in the lamination technique.

3.5 Modulus of elasticity

Statistical values of the modulus of elasticity of laminated and solid window profiles obtained as a result of the study are given in Table 7.

Table 7. Modulus of elasticity values

Statistical Value	Laminated Black Pine	Solid Black Pine
x(N/mm^2)	10330.9	9925.426
s(N/mm^2)	316.36	281.3246
V(s^2)	100089.65	79143.5375
min (N/mm^2)	9824.72	9524.36
max (N/mm^2)	11025.23	10356.02
N	20	10

x=arithmetic mean, v=variance, s=standard deviation, N=number of samples

The modulus of elasticity value of laminated black pine window profile was found to be higher than the solid window profile. Modulus of elasticity test results are shown in Figure 10.

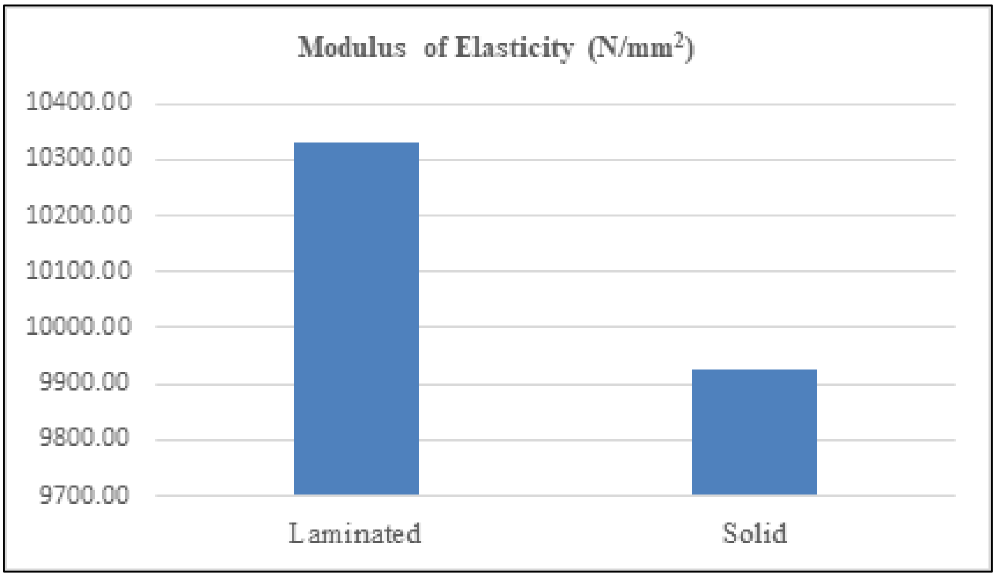

Figure 10. Modulus of elasticity histogram graph

In the literature, the elasticity modulus of solid Scots pine is stated as 10200 N/mm^2 (Toker, 1960). The elasticity modulus of the laminated black pine window profile was found to be higher than the modulus of elasticity of Scots pine. This may be due to the adhesive used in the lamination technique.

3.6 Determination of shear strength values

Statistical values of shear strength of laminated and solid window profiles are given in Table 8.

Table 8. Shear strength values

Statistical Value	Laminated Black Pine	Solid Black Pine
x(N/mm^2)	3.372	3.05
s(N/mm^2)	0.2068	0.15
v(s^2)	0.0428	0.0238
min (N/mm^2)	2.98	2.84
max (N/mm^2)	3.84	3.28
N	20	10

x=arithmetic mean, v=variance, s=standard deviation, N=number of samples

The shear strength value of laminated black pine window profile was found to be higher than that of solid window profile. The shear strength test results are shown in Figure 11.

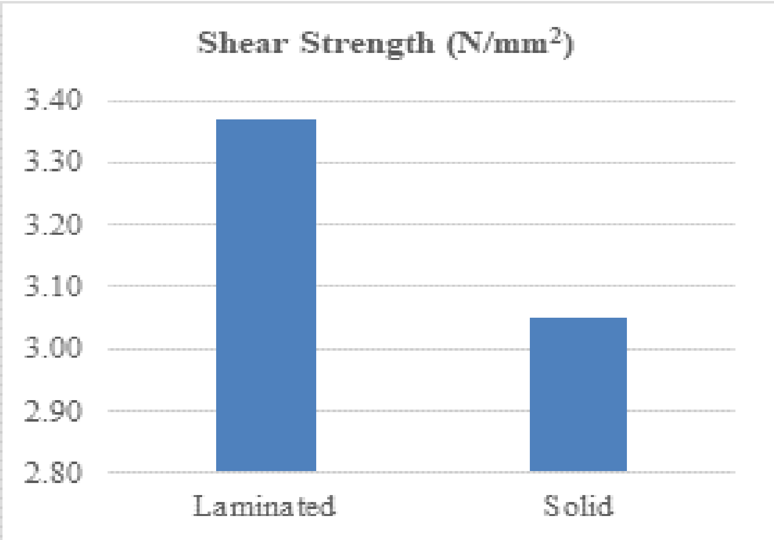

Figure 11. Shear strength histogram graph

The shear strength of the control samples employed in the experiment was lower than that of the laminated black pine window profile. This could be attributed to the adhesive applied in the lamination process which enhances the cohesive strength of the wood.

4 Conclusion

As a result of the research and the experiments carried out in the study;

- When the research results are examined, there is a potential for the use of Black pine (*Pinus nigra subsp*. pallasiana) wood in windows which is an integral element of living spaces in facade design. It can be evaluated that the laminated window profile made of black pine wood material is superior to the solid window profile in terms of its physical and mechanical properties, and can be preferred in window production.
- In Gratz and Solar's (1974) studies on window profiles, it was determined that the windows worked in outdoor weather conditions and did not fit into the frame causing them to bend.

Therefore, it can be shown as an advantage that the shrinkage amount of laminated window profiles is less than that of solid window profiles.

- It can be said that laminated profiles can be preferred more than solid materials by considering that laminated window profiles provide advantages over solid materials. In this context, the ability to produce window profiles in the desired colour and texture during lamination depending on the material to be used can provide choice flexibility for the consumer and pave the way for diversification of usage areas in architecture. Moreover, using wood material on window profiles also provides design flexibility depending on the facade type and building structure to the architects.
- In addition to the rational use of wood material, it is deemed beneficial to conduct versatile research on the increased use of laminated window profiles in our country in order to obtain a more durable, flawless, aesthetic and stable material compared to solid wood material. Research on thermal and electrical conductivity, acoustic properties, impregnation possibilities, resistance to various weather conditions, economical adhesives and their properties for laminated window profiles can contribute to our country by shedding light on practitioners.

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Author Contributions
Mustafa Kucuktuvek: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Supervision, Validation, Visualization, Writing – original draft. **Taner Asci**: Data curation, Formal Analysis, Methodology, Resources, Supervision, Visualization, Writing – review & editing. **Ahmet Şenel**: Conceptualization, Project administration, Resources, Supervision, Writing – review & editing.

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